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RADIATION EXPOSURES TO TECHNOLOGISTS FROM NUCLEAR MEDICINE IMAGING PROCEDURES

by

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Research report

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A research report prepared by R.S. Sloboda, M.G. Schmid and C.P. Willis, Pasqua Hospital, Regina, under contract to the Atomic Energy Control Board.

ABSTRACT

Radiation exposures incurred by nuclear medicine technologists during diagnostic imaging and gamma camera quality control (QC) were measured on a procedural basis over a three-month period using a portable, low-range, self-reading ion chamber. A total of more than 400 measurements were made for 15 selected procedures. From these, mean procedural exposures and standard deviations were calculated. The results show that daily flood phantom QC, at 0.58 mR, and gated cardiac studies, at 0.45 mR, were the two greatest sources of exposure. Other procedures resulted in exposures varying roughly from 0.10 to 0.20 mR. Difficult patients were responsible for a doubling of technologist exposure for many procedures. Standard deviations were large for all procedures, averaging 65% of the mean values. Comparison of technologist exposure inferred from the procedural measurements with the time coincident collective dose equivalent recorded by the TLD service of the Radiation Protection Bureau indicates that approximately half of the collective technologist exposure arose from patient handling and flood QC.

RÉSUMÉ

En médecine nucléaire, les techniciens sont soumis à des irradiations au cours d'examens diagnostiques et de procédures de contrôle de la qualité des appareils de gammagraphie. Un dosimètre à chambre d'ions portatif, à basse échelle et à lecture directe a été utilisé pendant trois mois pour mesurer ces irradiations. Plus de 400 mesures ont été faites pour 15 procédures données. Les expositions et les écarts types ont été calculés pour chaque procédure. Les résultats montrent que les essais quotidiens de contrôle de la qualité à l'aide de fantômes et que les études cardiaques synchronisées ECG dont l'exposition moyenne est de 0,58 mR et de 0,45 mR respectivement, représentent la plus grande source d'irradiation. Pour les autres procédures, l'exposition variait en gros entre 0,10 et 0,20 mR. Les patients plus difficiles font facilement doubler l'exposition des techniciens. Les écarts types sont dans chaque cas très élevés avec une moyenne de 65 pour 100 de la moyenne pour une procédure donnée. En comparant ces mesures avec l'équivalent de dose collectif enregistré par le Service national de dosimétrie du Bureau de la radioprotection pour la même période, on a pu montrer qu'approximativement la moitié de l'exposition totale des techniciens provenait de la manipulation des patients et des procédures de contrôle de la qualité.

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RADIATION EXPOSURES TO TECHNOLOGISTS FROM NUCLEAR MEDICINE IMAGING PROCEDURES

A. INTRODUCTION

Occupational radiation exposures to nuclear medicine technologists originate from a number of sources including generator elution, patient dose preparation and injection, and patient handling. Only within the past decade has it been observed that in a large number of radionuclide imaging procedures, the whole body exposure from patient handling can account for 50% or more of the total procedural exposure, when appropriate precautions are taken during dose preparation, assay, and injection[1-3].

The present investigation was primarily concerned with measuring technologist exposures arising from patient handling, for fourteen common diagnostic procedures routinely performed in a modern nuclear medicine department. In addition, technologist exposures resulting from daily flood phantom quality control (QC) of the scintillation cameras were also determined. In all over four hundred individual measurements were made, yielding information on mean procedural exposures from patient handling, their variability both in general and with respect to individual technologists, and their sensitivity to the degree of cooperation shown by the patients. To put these patient handling exposure measurements in perspective, they are compared with the results of earlier studies reported in the literature[1,3] and with time coincident radiation doses recorded by the TLD service of the Radiation Protection Bureau, Health and Welfare Canada.

B. DIAGNOSTIC PROCEDURES MONITORED

The patient handling components of fourteen diagnostic procedures were monitored, all of which involve imaging except for the thyroid uptake study. The procedures are listed in Table 1 along with an identifying code used in the data analysis, and the operative radionuclide. A short description of each procedure can be found in Appendix A. For the purposes of this study, patient handling was considered to involve escorting the patient from the waiting to the imaging area, positioning the patient for the imaging or counting procedure, performing that procedure, and finally escorting the patient out of the imaging area. Except for the brain flow procedure, which requires that an injection be given after the patient has been positioned, exposures due to radiopharmaceutical preparation and administration were not included in the patient handling measurements.

Besides patient handling by the technologists, the additional operation of flood phantom QC of the scintillation cameras, performed by the technologists on a daily basis, was monitored. Exposures arising from flood phantom QC, involving both phantom preparation and imaging, were measured on a procedural basis. The flood phantom QC protocol appears in Appendix A along with the descriptions of the diagnostic procedures.

C. DEPARTMENT LAYOUT

The nuclear medicine department in which the exposure measurements were taken is a modern, spacious facility housing three scintillation cameras, a thyroid uptake probe, and a rectilinear scanner used exclusively for thyroid scans.

Table 1: Diagnostic Procedures Monitored

No.	Procedure	Code	Radionuclide
1	Brain Flow	BF	Tc-99m
2	Brain Scan	BS	Tc-99m
3	Brain Tomography	BT	Tc-99m
4	Cardiac Wall Motion (rest)	CW	Tc-99m
5	Gallium Scan	GS	Ga-67
6	Lung Perfusion	LP	Tc-99m
7	Liver Scan	LS	Tc-99m
8	Liver Tomography	LT	Tc-99m
9	Lung Ventilation	LV	Xe-133
10	Spot Bone	SB	Tc-99m
11	Thallium Scan	TH	Tl-201
12	Thyroid Scan	TS	I-131
13	Thyroid Uptake	TU	I-131
14	Whole Body Bone	WB	Tc-99m

The layout of the department showing the placement of the diagnostic instrumentation and the location of the radiopharmacy, laboratory, and injection room is as depicted in Figure 1. The ample spacing of the instrumentation in conjunction with its distance from radiopharmaceutical supplies provides for generally very low background levels in the imaging area.

The scintillation cameras in the department represent a mix of old and new technology. A reconditioned Searle Pho Gamma IV, which has a standard field of view (280 mm), is used exclusively for cardiac work. The camera head is mounted on a T stand, with drive motors used for positioning. Since no counterbalancing is incorporated in the design, motion of the head is slow, and this in turn is reflected in the time required to set up a patient study. All of the remaining work is done using two General Electric 400A's which as their name suggests are large field of view (400 mm) cameras. One of them is mounted on a gimbal stand which rides on a whole body scanning track; the other on a ring stand suitable for tomographic studies. Both of these mountings employ counterbalancing, eliminating the need for drive mechanisms and allowing the technologist to manoeuver the head directly.

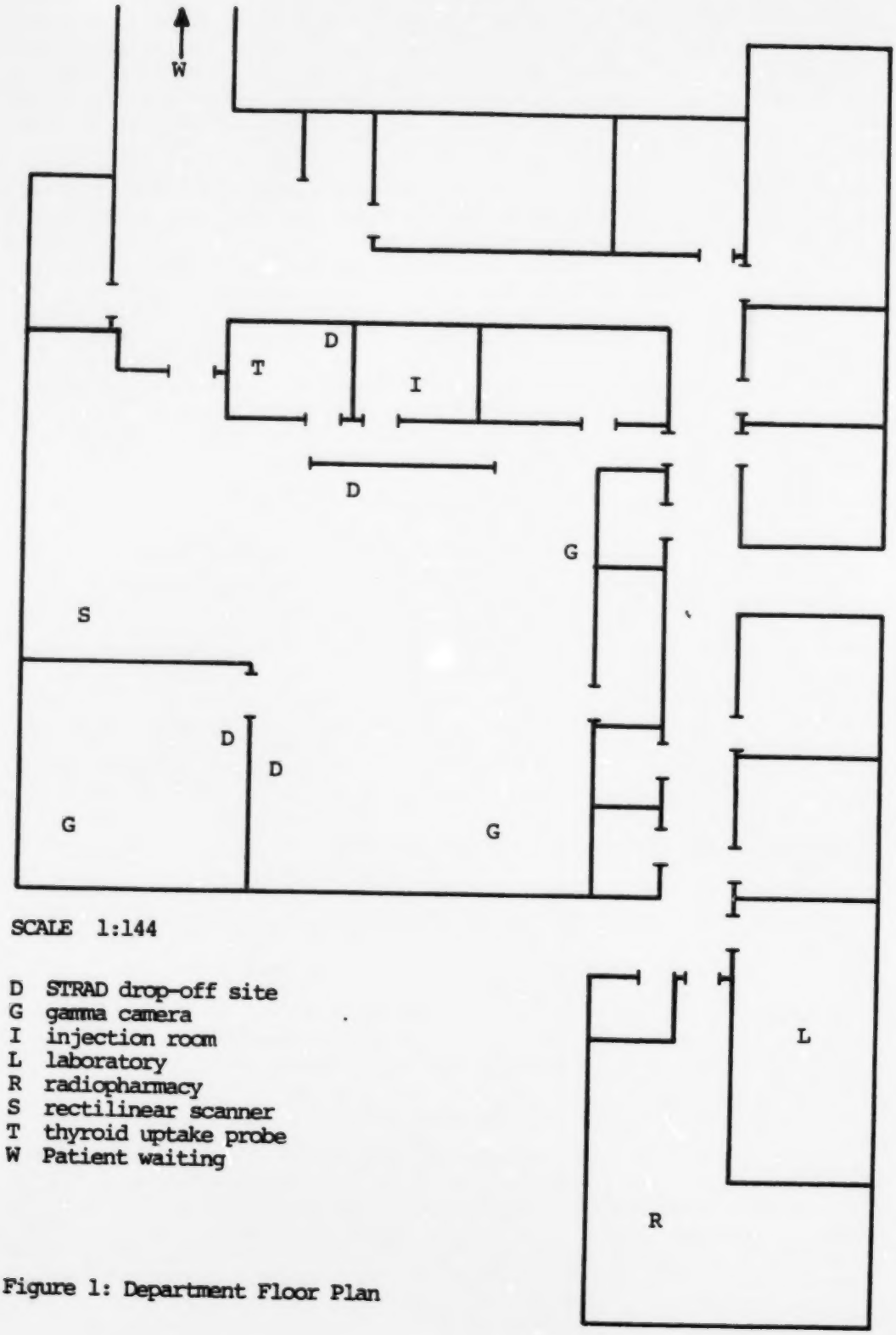
D. EXPOSURE MONITORING INSTRUMENTATION

All exposure measurements were made using the Dosimeter Corporation model 106 STRAD (Stray Radiation Dosimeter) ion chamber[4] shown in Figure 2. This battery-operated, portable, self-reading instrument possesses a range of 0 - 2 mR, with a factory calibrated accuracy of $\pm$ 15% at 120 KeV. According to the manufacturer, sensitivity is sufficient to measure 4 x background. The cylindrical unit measures approximately 8.8 inches in length by 3.0 inches in diameter, weighs about 6 pound, and has a chamber volume of 21.5 cubic inches. The chamber is not sealed, necessitating that temperature and pressure corrections be made to the readings. The variation in instrument response with with elevation angle and incident photon energy is shown in Figures 3 and 4, respectively. The angular response curve for 122 KeV was determined as described in Section D.1. All of the other information in these two figures was provided by the manufacturer.

Three STRAD units designated numbers 1, 2, and 3, calibrated according to the procedure described in section D.1, were used to measure individual technologist exposures. A pouch made of thin ripstop nylon sewn to the front of a bibbed apron, as shown in Figure 5, was used to hold one of the STRADs. The apron was worn by a technologist in such a manner that the center of the ion chamber approximately coincided with the bottom of the technologist's sternum. A drawstring at the top of the pouch secured the STRAD. Two such aprons were fabricated, enabling two measurements to be made concurrently.

1. Routine Calibration and Quality Control

A Co-57 calibration source whose activity during the exposure measurement period varied roughly between 2 and 3 mCi was used to determine STRAD calibration factors at bi-monthly intervals and to perform daily QC checks on the instruments. The Co-57 principal gamma energy of 122 KeV is close to both the STRAD's factory calibration energy of 120 KeV and the 140 KeV gamma ray emitted by Tc-99m, the most frequently used diagnostic radionuclide. The same source was also used to check the angular response of one of the STRADs both azimuthally and in elevation.



SCALE 1:144

D STRAD drop-off site
G gamma camera
I injection room
L laboratory
R radiopharmacy
S rectilinear scanner
T thyroid uptake probe
W Patient waiting

Figure 1: Department Floor Plan

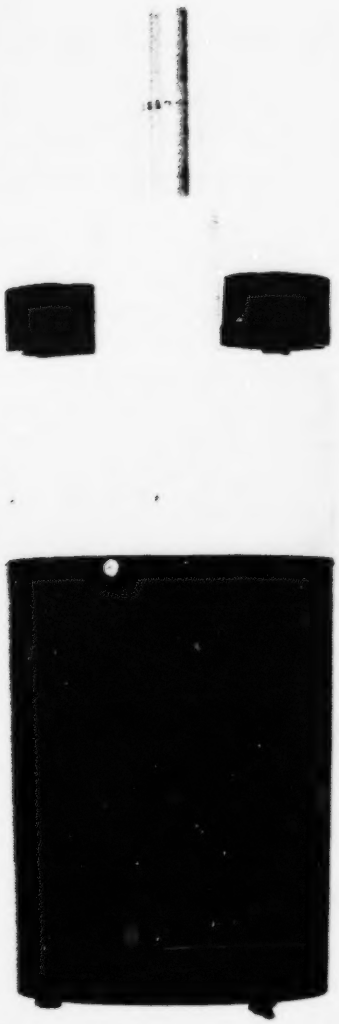


Figure 2: Model 106 STRAD ion chamber

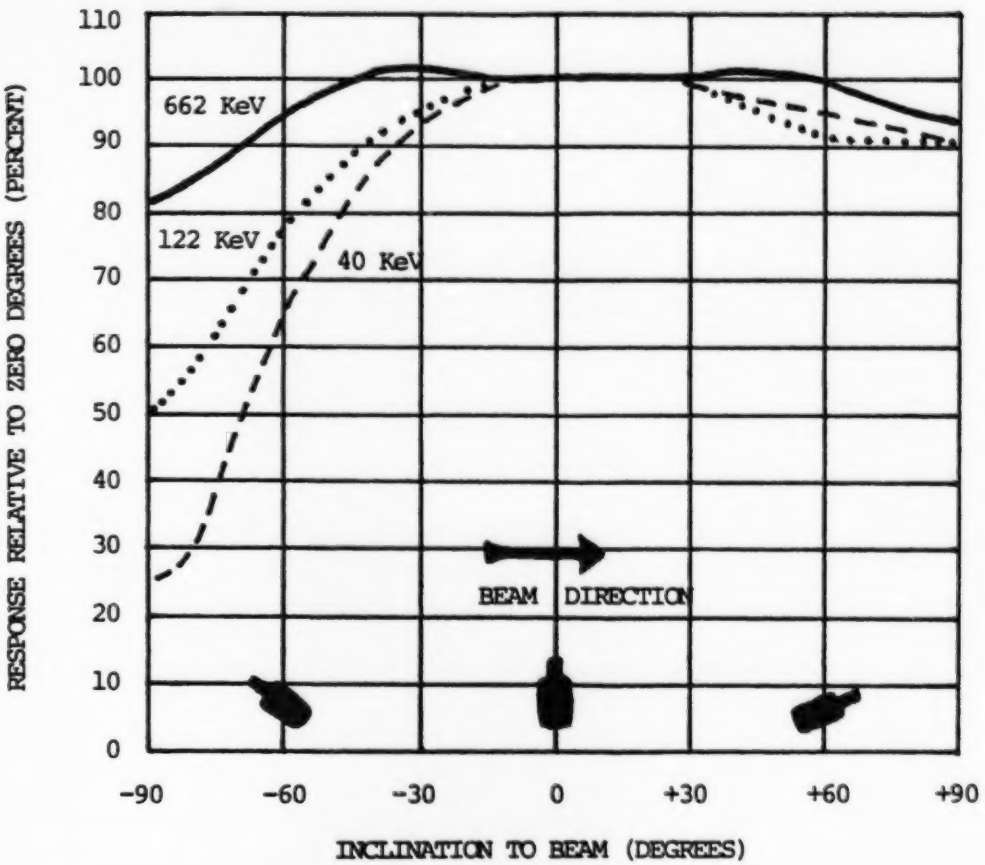


Figure 3: Angular Response of STRAD Dosimeter

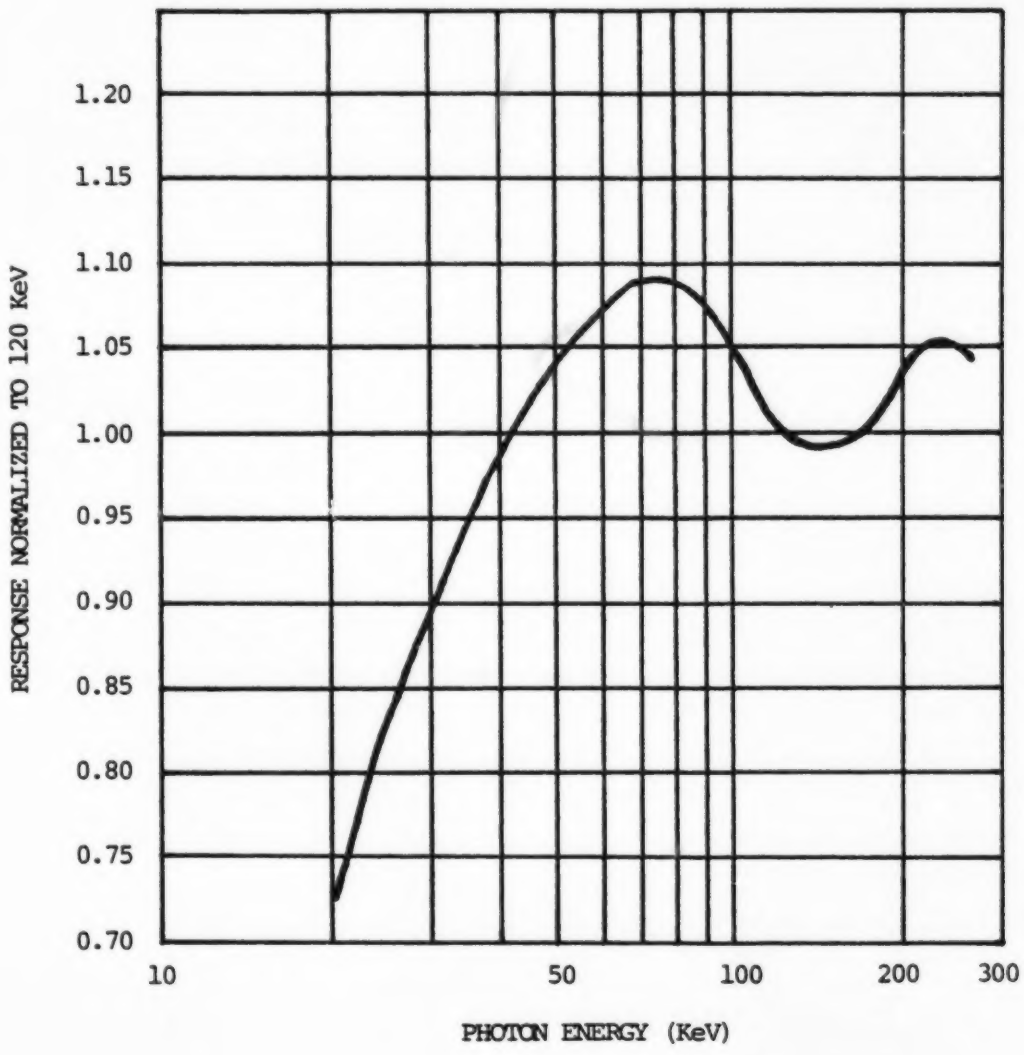


Figure 4: Energy Response of STRAD Dosimeter

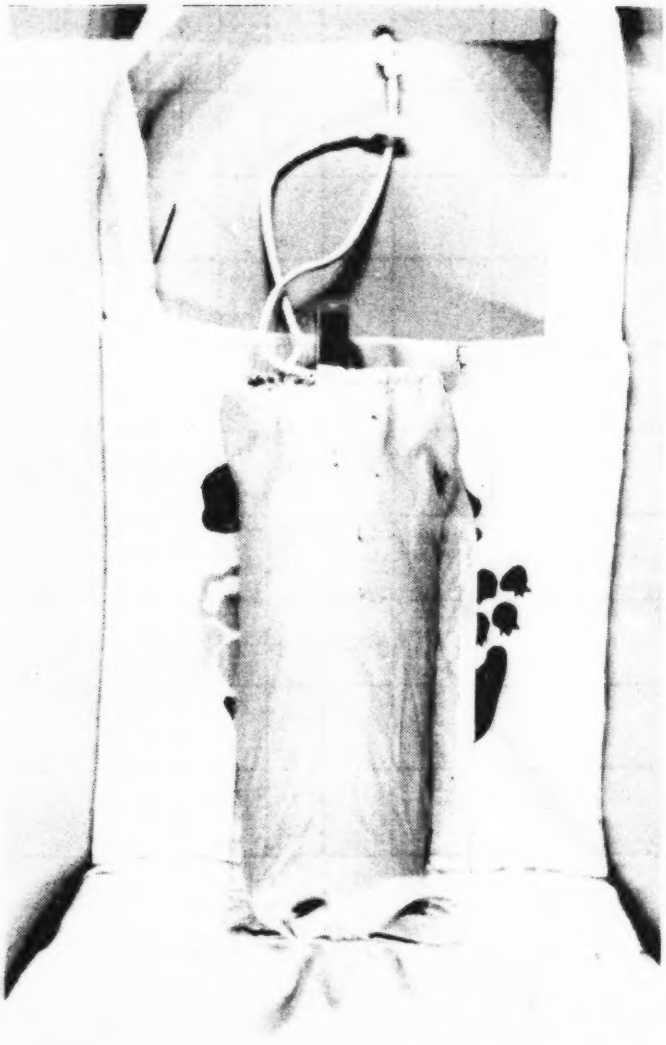


Figure 5: Apron and pouch holder for STRAD

For all of these measurements, source distances and measurement times were selected such that the readings would fall roughly at instrument mid-scale, ie. near 1 mR.

The angular response checks were performed with the source and STRAD positioned atop a level block of 6 inch thick styrofoam. For the azimuthal measurements, the upright STRAD was placed at a distance of 10 cm from the source, center to center. Readings of 2 minutes duration each were then taken at 20 degree intervals as the STRAD was rotated through a full circle. The resulting mean and standard deviation of the readings were 0.74 ± 0.01 mR, with no angular trend discernable. Our elevation measurements at 122 KeV were performed with the instrument lying on its side atop the styrofoam block at a distance (determined from the center of the chamber) of 45 cm from the source. Readings were taken at 15 degree intervals for an hour each while the instrument's top described a semi-circle, and corrected for background. The relative response is shown in Figure 3.

The daily quality control checks performed during the course of data collection involved placing the calibration source and STRAD atop the styrofoam block at distance of 10 cm and taking a 3 minute exposure reading. This was corrected for decay of the source and compared with previous readings. No temperature or pressure corrections were introduced, since the check was intended to be a rough one only. Generally speaking, the instruments displayed excellent stability. Expressed as percentages, the standard deviations in readings normalized by their mean values were 3.4%, 5.0%, and 3.7% for STRADs 1, 2, and 3, respectively.

The STRADs were calibrated at approximately two week intervals in order to determine appropriate calibration factors to be applied to the exposure readings from each instrument. The calibration source and STRAD were placed atop the syrofoam block at a distance of 45 cm, center to center. A reading was taken after one hour. The source was then removed, the instrument was zeroed, and next a one hour background and leakage reading was taken. The source reading corrected for background, temperature, and pressure was determined as follows:

$$S_C = (S - B) \times \frac{760}{P} \times \frac{T}{295} \qquad (1)$$

where: S_C = corrected source reading
S = raw source reading
B = raw background and leakage reading
P = atmospheric pressure in mm Hg
T = ambient temperature in degrees Kelvin

The expected source reading was calculated from the formula:

$$S_E = \frac{G\,A}{d^2} \qquad (2)$$

where: G = exposure rate constant in R cm^2 h^{-1} mCi^{-1}
A = source activity in mCi
d = STRAD to source distance, center to center, in cm

For Co-57, $G = 0.93$ R cm^2 h^{-1} mCi^{-1}. The calibration factor was calculated as:

$$C = S_E\, S_C^{-1} \qquad (3)$$

Table 2 contains the STRAD calibration factors determined over the course of the data collection period. For each instrument, the excellent stability of these values over time led us to use the average factors shown in Table 2 to correct the clinical exposure data.

Typical technologist procedural exposures as reported in the literature are in the 0.10 - 0.50 mR range[1], corresponding to the lower quarter of the STRAD scale. In order to determine the precision of the instrument and to verify its linearity within that range, an additional series of calibrations were performed retrospectively for STRAD 1. Different combinations of source distances and measurement times were employed to generate exposure rates and readings similar to the mean procedural values observed clinically (see Table 4). The results, summarized in Table 3, indicate that for the range 0.10 - 0.50 mR, instrument precision is at the level of 0.01 mR. Furthermore the instrument calibration factor, which is a measure of linearity, varies no more than $\pm$ 6%.

2. Energy Calibration

As evidenced by the entries in Table 1, the majority of the procedures monitored involve Tc-99m, which emits a 140 KeV gamma ray. Given the STRAD generic energy response curve in Figure 4 and the fact that our routine calibration factors were obtained at 122 KeV, it is evident that no additional energy correction factor is required for Tc-99m. For the lung ventilation studies involving Xe-133 with principal photon energies of 31 KeV (39% abundance) and 81 KeV (37% abundance), the energy correction is estimated to be only a few percent at most. For the myocardial perfusion studies involving Tl-201 with principal photon energies of 69 and 71 KeV, Figure 4 indicates that an energy correction factor of 0.93 (1/1.08) is appropriate. For studies involving Ga-67 or I-131, both of which emit at least one photon having an energy above 240 KeV, Figure 4 is incomplete. For these radionuclides a one time energy calibration using the method described in Section D.1 was performed. Sources of Ga-67 and I-131 assayed in a dose calibrator to an accuracy of 5% were monitored using STRAD number 3, yielding energy correction factors of 1.02 and 1.11, respectively.

E. EXPOSURE MEASUREMENTS

Three model 106 STRAD dosimeters were employed to monitor diagnostic and quality control exposures. For most of the three month measurement period, two of the units were in service concurrently, permitting two diagnostic procedures to be monitored simultaneously. As a whole the STRADs performed well, exhibiting good stability and reliability, as evidenced by the instrument QC and calibration results of Section D.1. Two specific problems were encountered with the ion chambers, however. The first, involving excessive leakage in unit number 1, was detected during daily QC. The difficulty was promptly remedied by baking out the unit at 50 degrees C for 48 hours, as per the manufacturer's instructions. The second problem involved loss of the quartz fiber in the electrometer section of unit number 2, necessitating it's shipment back to the manufacturer for repair under warranty.

The pouch and apron holders for the STRADs proved very serviceable. Technologist participation in the design of these was largely responsible for their functionality and acceptability.

Table 2: STRAD Calibration Factors

Date	Unit #1	Unit #2	Unit #3
June 4	1.014		
June 17		1.141	
July 5	0.978	1.158	
July 15			1.152
July 30		1.180	1.160
Aug 15		1.155	1.160
Aug 30			1.153
Average	1.00	1.16	1.16

Table 3: Precision and linearity of STRAD number 1, as gauged by maximum reading deviations and instrument calibration factors, respectively. Six readings were taken for each different combination of source distance and measurement time, and corrected as per Equation (1). Exposure rates were calculated from Equation (2).

Source Distance (cm)	Measurement Time (min)	Exposure Rate (mR/hr)	Mean Reading (mR)	Maximum Deviation (mR)	Calibration Factor
20	4	3.24	0.21	0.01	1.05
45	15	0.64	0.17	0.01	0.95
45	60	0.64	0.64	0.01	0.99 *
70	30	0.26	0.13	0.01	1.01
70	60	0.26	0.26	0.01	0.98

* denotes setup corresponding to the standard calibration protocol

1. Patient Handling

As a general rule, the patient handling exposure measurements for each of the procedures enumerated in section B included the following actions on the part of the attending technologist:

(1) Escorting the patient from the waiting area to the imaging room. Depending on the patient's condition, the technologist may transport the patient on a stretcher, push him in a wheelchair, take his arm, or simply show him the way.

(2) Assisting the patient onto the imaging bed or stool. The amount of assistance which is necessary will vary. The technologist may lift a stretcher patient onto the bed, assist a patient from a wheelchair, steady a patient by holding his arm as he moves by himself, or provide no assistance at all.

(3) Assisting the patient to sit or lay in the required position in front of the camera, scanner, or counting probe for each view. The technologist may be required to simply explain to the patient how to position himself, or it may be necessary to move the patient into position and perhaps hold him there for the duration of the procedure.

(4) Assisting the patient from the imaging bed or stool when the procedure is complete and escorting him back to the waiting area. Again the amount of assistance required will vary with the patient's condition.

For each procedure monitored, the measurement process involved the following sequence of operations:

(1) Prior to the technologist meeting the patient, a STRAD was zeroed and placed into the pouch designed to accomodate it affixed to the front of an apron worn by the technologist, as described in Section D.

(2) During the diagnostic procedure the dosimeter remained with the technologist at all times, unless the technologist was required to perform a task unrelated to the procedure (for instance helping to lift another patient from a stretcher). In this latter case the technologist first proceeded to a designated drop-off station, where the dosimeter remained for the duration of the unrelated activity, and later recovered the instrument prior to returning to the original patient. A drop-off station was assigned for each diagnostic instrument, as indicated in Figure 1. These sites, taking the form of desks or countertops, were locations from which the technologist would normally observe the patient when not otherwise engaged.

(3) At the completion of the procedure, the dosimeter was recovered and read. The reading, along with certain ancillary information, was recorded on a data sheet like the one in Appendix B. The additional information included the elapsed time, background reading, attending technologist, difficulty handling the patient, etc. The data sheet information fields are fully described in Appendix B.

For the first procedures monitored, an individual half-hour background reading was acquired for each exposure measurement, however it soon became apparent that background levels throughout the imaging area were very low, being consistent with the STRAD background and leakage readings obtained during instrument calibrations. The low levels are due to the large distances separating the individual imaging locations, and their collective removal from areas of radiophamaceutical preparation and handling, as mentioned in Section C and illustrated in Figure 1. Subsequently background readings of one hour in duration were acquired once or twice daily as the patient workload permitted, enabling more time to be devoted to the exposure measurements themselves.

Patient handling difficulty was judged by the attending technologist on a scale of 1 - 5 with 1 = easy, 3 = average, and 5 = difficult. Prior to the start of clinical data collection, the technologists as a group were instructed to exercise their own judgement in assessing how much time they needed to spend close to the patient compared with the norm for that procedure, and to use that criterion to assign a number to the handling difficulty data field.

In total, 395 patient handling exposure measurements were made over a three month period from June through August, 1985.

2. Flood Phantom Quality Control

Regular instrument quality control procedures are an integral part of the routine in most nuclear medicine departments. In the department monitored, gamma camera uniformity was checked on a daily basis by acquiring static images of flood phantoms. Two phantoms were used; a large one for the two large field of view cameras and another smaller one for the standard field of view camera. The commercially available phantoms consist of a flat, thin-walled Lucite box enclosing a squat cylindrical volume with a cross section large enough to cover the camera field of view. The phantoms were each filled daily with 5 - 8 mCi of Tc-99m and water, agitated manually in order to mix the contents uniformly, and then positioned at the cameras for imaging. The entire procedure, performed first thing every morning prior to the arrival of patients, is fully described in Appendix A.

The preparation of both phantoms as well as their imaging was included in the exposure measurement, since the preparation involved handling unshielded activities somewhat analagously to patient handling. A zeroed STRAD was placed in its pouch on an apron worn by the technologist prior to the start of the quality control procedure, and recovered after the flood phantoms were placed in their lead-lined storage container at completion. The instrument reading and ancillary information, as described in Appendix B, were recorded for analysis. A total of 25 flood phantom QC procedures were monitored.

F. DATA ANALYSIS

For both the diagnostic and flood phantom quality control procedures, data was transcribed onto an IBM PC for analysis. The commercially available SMART Data Manager[5] software package provided complete transcription, archival, analysis, and report generation capabilities. The Data Manager's project processing feature, a stored program facility resembling the BASIC programming language, was used to perform the required data manipulations.

1. Patient Handling

Patient handling exposure measurements were transcribed from the data sheets described in Appendix B into a SMART data base having corresponding information fields. An additional field, denoted the corrected exposure reading, was included in the data base definition, to be filled in later by the analysis software. Transcription was facilitated by the use of a custom data entry screen, which exactly duplicated the format of the data sheets. A total of 395 data base records, one for each data sheet, were created in this fashion.

In the first phase of data analysis, corrected exposure readings were calculated and entered into the extra data base field reserved for this purpose. The corrected readings were determined as:

$$R' = C_N \times C_E \times \left(\frac{760}{P}\right) \times \left[R - \left(B \times \frac{Tr}{Tb}\right)\right] \qquad (4)$$

where: C_N = average Co-57 calibration factor for STRAD number N as per Table 2
C_E = radionuclide-specific energy calibration factor
P = atmospheric pressure in mm Hg
R = exposure reading in mR
B = background reading in mR
Tr = length of time for exposure reading in min
Tb = length of time for background reading in min

The energy calibration factor C_E is intended to compensate for variations in STRAD response at the different radionuclide photon energies. As shown in Section D.2, however, this factor is unity to within a few percent for Tc-99m, Xe-133, and Ga-67. Since our exposure measurements are no more accurate than this, C_E can be set equal to 1.0 for these radionuclides. For Tl-201 and I-131 however, this is not the case; in Section D.2 the energy correction factors of 0.93 and 1.1 respectively, were indicated as being appropriate. In reviewing the raw exposure data, however, the average readings for both Tl-201 and I-131 are very low, being about 0.05 mR for the thallium studies and 0.01 mR for the thyroid scans and uptakes. STRAD readings of this magnitude contain only one significant figure, hence corrections at the level of 10% or less can be ignored since they represent changes to which the instrumentation is insensitive. Consequently the energy calibration factor C_E was set equal to unity for all radionuclides dealt with in this study. No temperature correction was required since the climate-controlled department was maintained at a constant 22 degrees C. Calculation of the corrected exposure readings and their entry into the data base was performed by a dedicated program created via the SMART Data Manager's project processing facility. Listings of this and other software programs used in the data analysis can be found in Appendix C.

The second phase of data analysis involved the extraction of statistical information from the set of corrected exposure readings plus ancillary data. Several software programs were created to access the exposures data base, perform specific calculations using data from it, and output the results to secondary data base files from which reports could be generated.

In one program, the mean values and standard deviations of corrected exposure readings for each diagnostic procedure were calculated.

The approach used involved first forming the sum and sum of squares of the 'n' readings for a given procedure:

$$S = \text{sum } R_i' \quad ; i = 1,2,...n \tag{5}$$

$$SS = \text{sum } (R_i')^2 \quad ; i = 1,2,...n \tag{6}$$

and from these obtaining the mean and standard deviation as follows:

$$\text{mean} = S/n \tag{7}$$

$$\text{s.d.} = [(SS - S^2/n)/(n-1)]^{0.5} \tag{8}$$

In another program, mean values and standard deviations of corrected exposure readings for normal and difficult patients separately were determined for each diagnostic procedure monitored. The normal patients were those for which the attending technologist recorded a 1, 2, or 3 in the positioning difficulty field. The difficult patients were those receiving a 4 or 5 in the same field. Except for the distinction on the basis of positioning difficulty, the calculations proceeded exactly as for the program previously described, with Equations 5 - 8 applying.

The last processing program relating to patient handling involved the calculation of corrected exposure reading mean values and standard deviations for each individual technologist for each diagnostic procedure. The approach summarized in Equations 5 - 8 was again used.

In the third and final phase of data analysis, the results held in the secondary data base files were compiled into reports, using the report generation feature of the SMART Data Manager. Printed in tabular form, these reports present statistical information extracted from the exposures data base in a concise format.

2. Flood Phantom Quality Control

Flood phantom quality control measurements were transferred from the data sheets described in Appendix B to a SMART data base with corresponding data fields. An additional field for the corrected exposure reading was created for use by the analysis software. Twenty-five records, one for each data sheet, comprised the completed data base.

Corrected exposure readings were calculated as:

$$R' = C_N \times \frac{760}{P} \times [R - (Bi \times \frac{Ti}{30}) - (Bl \times \frac{Tl}{30})] \tag{9}$$

where: C_N = average Co-57 calibration factor for STRAD number N as per Table 2
P = atmospheric pressure in mm Hg
R = exposure reading in mR
Bi = 30 min imaging area background reading in mR
Bl = 30 min lab background reading in mR
Ti = measurement time spent in imaging area in min
Tl = measurement time spent in lab in min

No temperature correction was required since the department was maintained at 22 degrees C.

A dedicated SMART Data Manager program was created to calculate the corrected exposure readings. The mean flood phantom quality control exposure and standard deviation were determined from the corrected readings using the methodology described in Section F.1. A second program was written to access the corrected readings, perform the statistical calculations, and output the values to a secondary data base file for inspection.

G. RESULTS

In this section the results of the current investigation are presented and discussed, then compared with dose estimates obtained by the TLD service of the Radiation Protection Bureau, Health and Welfare Canada. The latter exercise represents an attempt to assess what fraction of total technologist exposures were attributable to patient handling and quality control during the monitoring period. Finally the results obtained here are compared with those of similar investigations reported in the literature.

1. Present Exposure Measurements

The results of analysing the patient handling exposure measurements in the manner described in Section F.1 are summarized in Tables 4, 5, and 6.

Table 4 gives the mean exposure and standard deviation for each of the diagnostic procedures listed in Table 1, along with the number of measurements and mean imaging time. It is immediately apparent that the cardiac wall motion studies contribute the most to technologist exposure on a per procedure basis, while the thyroid scan and uptake contribute the least. Both of these findings may be readily explained. For the cardiac wall motion studies the relatively large amount of activity used (20 mCi), in combination with the length of time which the technologist must spend close to the patient carefully positioning him for four sequential views, accounts for the exposure. The positioning time in this particular instance is partially determined by the instrumentation: the cardiac camera's motor-driven T stand makes camera head positioning a tedious operation compared with the counterbalanced heads of the other two cameras, which can be manoevered manually. For the thyroid uptakes and scans, the small amount of activity involved (50 uCi), which is roughly two orders of magnitude below that for most camera imaging procedures, translates into a very low technologist exposure which is consistent with zero insofar as instrumental accuracy is concerned. Except for thallium myocardial perfusion studies, which again result in low exposures due to the small amount of activity present and the significant bodily attenuation of the approximately 70 KeV photons, the remaining average procedural exposures fall roughly within the range from 0.10 to 0.20 mR.

Particularly noteworthy are the relatively large standard deviations for all procedures, which vary from 33% of the mean value for cardiac wall motions to 109% for the lung perfusion studies. The standard deviation for the majority of procedures, however, is relatively constant at about 65% of the mean value. One might have expected a certain amount of variability a priori on the basis of differences in patient uptake of the radiopharmaceutical, patient cooperation, and individual technologist working habits. The results in Table 4 confirm that such variability is present to a considerable extent for all diagnostic procedures. Instrumental uncertainty is limited to approximately 10%, as indicated in Table 3, and thus contributes only a small amount to the observed standard deviations.

Table 4: Procedural Exposure Mean Values and Standard Deviations

Procedure Code	Description	No. of Studies	Mean Exposure (mR)	Standard Deviation (mR)	Mean Time (min)
BF	Brain flow	28	0.19	0.13	4
BS	Brain scan	23	0.21	0.13	25
BT	Brain tomography	11	0.16	0.11	51
CW	Cardiac wall motion	33	0.45	0.15	43
GS	Gallium scan	6	0.06	0.03	61
LP	Lung perfusion	31	0.11	0.12	13
LS	Liver scan	9	0.11	0.07	29
LT	Liver tomography	30	0.09	0.06	32
LV	Lung ventilation	29	0.13	0.08	16
SB	Spot bone	28	0.11	0.11	31
TH	Thallium scan	30	0.04	0.04	32
TS	Thyroid scan	28	0.01 *	0.01	13
TU	Thyroid uptake	25	0.01 *	0.02	6
WB	Whole body bone	84	0.15	0.11	51

* denotes values consistent with zero

Of the 395 patient studies monitored, 49 (roughly 12%) were identified by the technologists as involving difficult patients according to the criteria outlined in Section E.1. Table 5 contains the procedural mean values and standard deviations for both the average and difficult patient groups considered separately. For the brain flow, lung ventilation, and thallium studies, exposures in the difficult group did not differ significantly from those in the average group as gauged by the Student t-test. For all other procedures involving difficult patients, however, higher exposures for the difficult group were confirmed by the t-test as being significant at the 10% level for brain tomography and cardiac wall motion studies, and at the 5% level or better for all remaining studies. The increases ranged roughly from 30% to 200% and were not always reflected in the mean imaging times, the brain scan procedure being a good example of this. The lack of an increase in technologist exposures in the case of difficult lung ventilation patients may be understood in that the Xe-133 gas is only administered after the patient has been initially positioned; thus problems related to initial positioning and to acclimatizing the difficult patient to the breathing apparatus do not normally involve the technologist being exposed to radiation for greater lengths of time than for average patients. Similarly for the brain flow studies, administration of the radiopharmaceutical is only done after the patient's head has been immobilized. The very low exposures for the thallium studies render an average/difficult comparison somewhat meaningless. For the majority of procedures, the standard deviation expressed as a percentage of the mean value for the average patient group is nearly the same as for both groups considered together (see Table 4). This implies that other factors besides patient cooperation are also responsible for the observed variability in technologist exposures.

Table 6 contains a breakdown of technologist exposures by procedure and by individual technologist. The same information on technologist mean exposures is presented graphically in Figure 6 for selected procedures. It can be observed that for the brain and lung imaging procedures, technologist mean exposures are quite variable, while for the cardiac wall motion studies and whole body bone scans, they are much less so. The reason for this may lie in the nature of the procedures themselves: cardiac wall motion and whole body bone scan setups are done in a fairly mechanistic fashion, while brain and lung studies are somewhat more variable in terms of setup time and the requirement for ongoing close technologist attendance to the patient during imaging. For all procedures, however, the standard deviations are again large compared with the mean values for all technologists handling more than a few patients. This finding strongly supports the idea that procedural variability in exposure arises mostly due to some combination of the variation in patient uptake of the radiopharmaceutical and the unique demands which each patient places on the technologist, and is rather less dependent on individual technologist working habits. If the latter were true, one would expect to see low standard deviations for some of the procedures for at least one of the technologists. Further support for this view is to be found from the whole body bone scan results. These are based on the greatest number of studies monitored for any of the procedures, and therefore represent the most statistically accurate information in Table 6. For the whole body bone scans, four technologists who had each handled fifteen patients or more were monitored. The very similar mean values and standard deviations determined for these four technologists suggest that procedural exposure variability is not primarily dependent on technologist working habits.

Table 5: Procedural Exposure Mean Values and Standard Deviations for Average and Difficult Patients

Procedure Code	Patient Positioning	No. of Studies	Mean Exposure (mR)	Standard Deviation (mR)	Mean Time (min)
BF	Average	22	0.18	0.12	4
	Difficult	6	0.23	0.13	4
BS *	Average	20	0.17	0.08	26
	Difficult	3	0.47	0.04	19
BT +	Average	8	0.13	0.08	50
	Difficult	3	0.25	0.15	54
CW +	Average	30	0.44	0.13	43
	Difficult	3	0.59	0.22	48
GS *	Average	6	0.06	0.03	61
	Difficult	0	0.00	0.00	0
LP *	Average	24	0.09	0.07	12
	Difficult	7	0.19	0.20	14
LS *	Average	7	0.08	0.05	29
	Difficult	2	0.20	0.07	28
LT *	Average	27	0.08	0.03	29
	Difficult	3	0.18	0.16	58
LV	Average	26	0.13	0.08	16
	Difficult	3	0.12	0.10	14
SB *	Average	23	0.08	0.06	29
	Difficult	5	0.25	0.19	41
TH	Average	28	0.04	0.05	32
	Difficult	2	0.01	0.01	27
TS	Average	28	0.01	0.02	13
	Difficult	0	0.00	0.00	0
TU	Average	25	0.01	0.02	6
	Difficult	0	0.00	0.00	0
WB *	Average	72	0.12	0.08	51
	Difficult	12	0.32	0.13	51

* difference significant at the 5% level
+ difference significant at the 10% level

Table 6: Procedural Exposure Mean Values and Standard Deviations for Individual Technologists

Procedure Code	Technologist	No. of Studies	Mean Exposure (mR)	Standard Deviation (mR)	Mean Time (min)
BF	CF	0	0.00	0.00	0
	DS	7	0.21	0.13	3
	LG	9	0.14	0.07	5
	LK	10	0.21	0.16	4
	LL	0	0.00	0.00	0
	RJ	1	0.37	0.00	3
	RN	1	0.14	0.00	5
	SF	0	0.00	0.00	0
BS	CF	2	0.28	0.22	27
	DS	6	0.28	0.19	20
	LG	7	0.20	0.07	30
	LK	5	0.10	0.03	22
	LL	0	0.00	0.00	0
	RJ	1	0.23	0.00	22
	RN	2	0.23	0.03	29
	SF	0	0.00	0.00	0
BT	CF	2	0.09	0.12	51
	DS	3	0.28	0.13	49
	LG	3	0.15	0.02	51
	LK	2	0.12	0.08	55
	LL	1	0.06	0.00	53
	RJ	0	0.00	0.00	0
	RN	0	0.00	0.00	0
	SF	0	0.00	0.00	0
CW	CF	5	0.42	0.13	40
	DS	5	0.38	0.10	43
	LG	4	0.54	0.10	38
	LK	10	0.48	0.13	49
	LL	3	0.56	0.24	38
	RJ	6	0.40	0.18	42
	RN	0	0.00	0.00	0
	SF	0	0.00	0.00	0
GS	CF	1	0.09	0.00	38
	DS	2	0.08	0.01	75
	LG	1	0.00	0.00	49
	LK	1	0.04	0.00	50
	LL	0	0.00	0.00	0
	RJ	1	0.05	0.00	80
	RN	0	0.00	0.00	0
	SF	0	0.00	0.00	0

Table 6: Procedural Exposure Mean Values and Standard Deviations for Individual Technologists (continued)

Procedure Code	Technologist	No. of Studies	Mean Exposure (mR)	Standard Deviation (mR)	Mean Time (min)
LP	CF	5	0.14	0.14	18
	DS	12	0.07	0.03	12
	LG	2	0.12	0.02	14
	LK	6	0.19	0.22	12
	LL	2	0.09	0.01	9
	RJ	4	0.09	0.03	12
	RN	0	0.00	0.00	0
	SF	0	0.00	0.00	0
LS	CF	1	0.15	0.00	118
	DS	4	0.09	0.05	24
	LG	3	0.14	0.10	12
	LK	0	0.00	0.00	0
	LL	0	0.00	0.00	0
	RJ	1	0.03	0.00	9
	RN	0	0.00	0.00	0
	SF	0	0.00	0.00	0
LT	CF	6	0.15	0.10	43
	DS	6	0.06	0.04	30
	LG	2	0.09	0.00	28
	LK	7	0.08	0.03	27
	LL	2	0.09	0.02	27
	RJ	7	0.06	0.03	30
	RN	0	0.00	0.00	0
	SF	0	0.00	0.00	0
LV	CF	2	0.05	0.04	22
	DS	14	0.12	0.08	15
	LG	4	0.14	0.05	15
	LK	4	0.10	0.06	15
	LL	0	0.00	0.00	0
	RJ	4	0.18	0.02	17
	RN	1	0.30	0.00	16
	SF	0	0.00	0.00	0
SB	CF	7	0.11	0.14	25
	DS	4	0.17	0.22	33
	LG	2	0.10	0.04	50
	LK	9	0.07	0.04	30
	LL	0	0.00	0.00	0
	RJ	5	0.14	0.09	33
	RN	1	0.20	0.00	44
	SF	0	0.00	0.00	0

Table 6: Procedural Exposure Mean Values and Standard Deviations for Individual Technologists (continued)

Procedure Code	Technologist	No. of Studies	Mean Exposure (mR)	Standard Deviation (mR)	Mean Time (min)
TH	CF	4	0.03	0.02	32
	DS	6	0.04	0.02	28
	LG	2	0.01	0.01	34
	LK	9	0.04	0.02	32
	LL	1	0.02	0.00	24
	RJ	4	0.11	0.10	38
	RN	4	0.03	0.01	31
	SF	0	0.00	0.00	0
TS	CF	0	0.00	0.00	0
	DS	11	0.01	0.02	11
	LG	2	0.01	0.01	18
	LK	4	0.00	0.00	10
	LL	1	0.01	0.00	16
	RJ	10	0.02	0.01	15
	RN	0	0.00	0.00	0
	SF	0	0.00	0.00	0
TU	CF	0	0.00	0.00	0
	DS	3	0.00	0.00	6
	LG	6	0.03	0.02	6
	LK	2	0.00	0.00	6
	LL	0	0.00	0.00	0
	RJ	2	0.02	0.02	6
	RN	0	0.00	0.00	0
	SF	12	0.01	0.01	6
WB	CF	23	0.13	0.10	58
	DS	17	0.16	0.13	49
	LG	6	0.15	0.06	48
	LK	15	0.16	0.10	48
	LL	4	0.11	0.07	31
	RJ	19	0.17	0.13	50
	RN	0	0.00	0.00	0
	SF	0	0.00	0.00	0

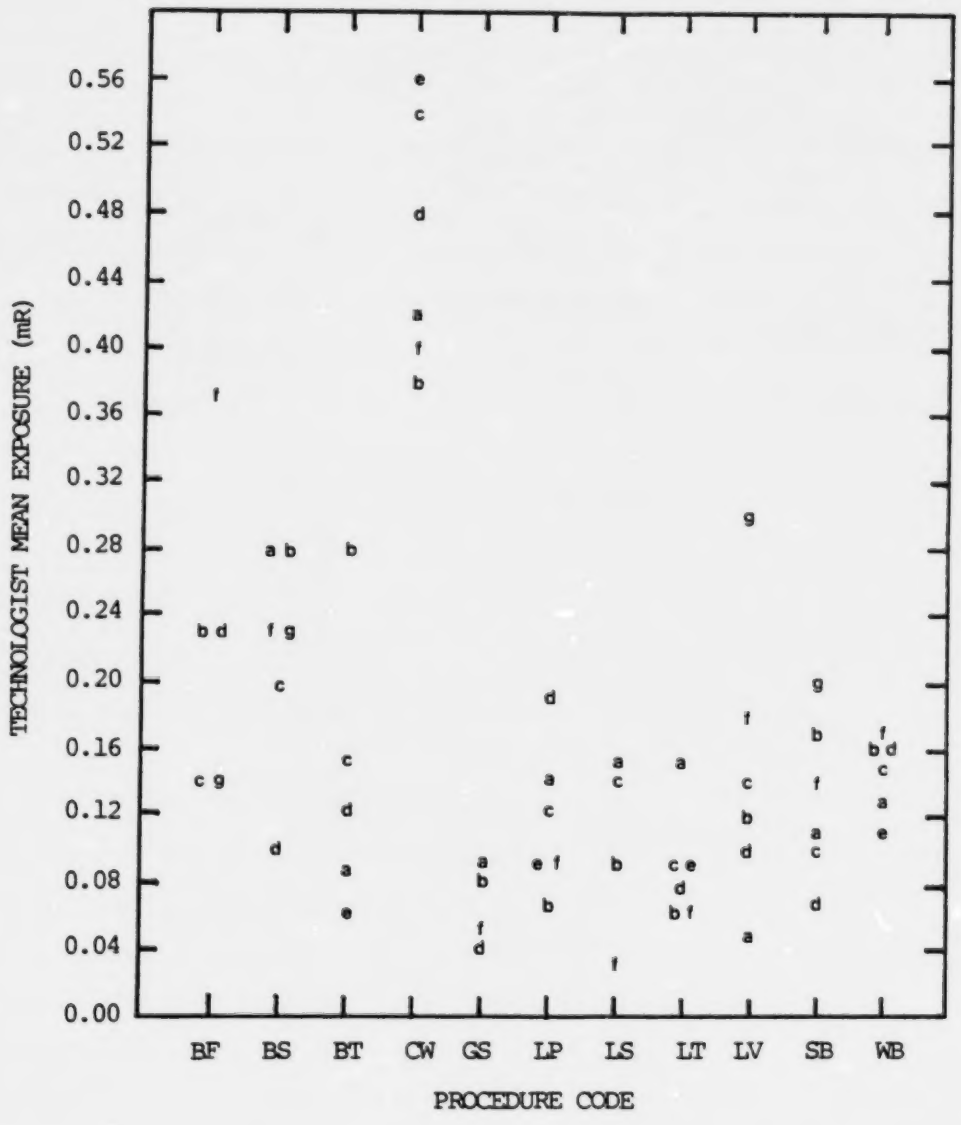


Figure 6: Scatter plot of technologist mean exposure by procedure. Technologists are coded a-h.

Further examination of Figure 6 reveals that no one technologist consistently received higher procedural exposures than the others. Apart from considerations relating to working habits, the lack of such a trend reflects the similarity in size and stature of the technologists. Excluding the chief technologist, who participated in relatively few of the exposure measurements, and another senior technologist, who mainly performed thyroid studies, the technologists only ranged in height from 157 - 165 cm, and in weight from 55 - 65 kg.

The overall accuracy of the corrected exposure readings individually is estimated to be about 10% for readings of 0.15 mR or greater and about 20% for readings in the vicinity of 0.10 mR. At Tc-99m energies, the STRAD calibration factor varies only $\pm$ 6% for our clinical exposure rates and readings, however the variation in response with inclination angle (see Figure 2) indicates that our diagnostic exposure measurements may in some circumstances be slight underestimates. Since in the clinical situation inclination angles less than -40 degrees (a significant source of activity exists within an imaginary 40 degree cone emanating from the top of the instrument and axially coincident with it) are very uncommon, and if present at all usually exist only for a short time (the technologist must bend over to tie a shoelace, for instance), inaccuracies should be confined to the levels cited above. Furthermore the anterior wearing of the STRADs will to some extent offset this latter bias since the instruments are virtually always placed closer to the patient than the technologist, and thus will encounter slightly higher radiation fields.

The average daily flood phantom QC exposure was determined to be 0.58 $\pm$ 0.10 mR, with two flood phantoms in use for the three gamma cameras, as described in Appendix A.

2. Comparison with RPB Records

All of the nuclear medicine technologists who participated in the present study were classified as atomic radiation workers during the data collection period. The dose equivalents which they received were regularly monitored on a quarterly basis by the TLD service of the Radiation Protection Bureau, Health and Welfare Canada. The department in which the measurements were taken falls into group G in the RPB classification scheme, hence a report is available for the time period June 15 - September 14, 1985, a time period corresponding closely to the study's June 1 - August 31 data collection interval. The information contained in the RPB report, when combined with the mean procedural exposures measured and the numbers of each procedure performed during the RPB monitoring period, permit an estimate to be made of the fraction of a technologist's exposure attributable to patient handling and flood phantom quality control.

The RPB collective dose equivalent for the eight participating technologists measured over the period June 15 - September 14 is 480 mrem, with each of the technologists in question having been assigned a dose in excess of the 20 mrem reporting threshold. Since the technologists are exposed virtually exclusively to gamma photons, the corresponding exposure estimate is 480 mR. An estimate of the collective technologist exposure due to patient handling is obtained by multiplying mean procedural exposures by the number of times the procedures were performed during the RPB recording period, and then summing the results.

The actual situation was slightly more complicated since the technogists were also employed on a rotating basis in a second single-camera nuclear medicine department, but only wore a single TLD badge in both locations. If the assumption is made that the same procedural mean exposures were operative in the second department, and the number of studies done there is included in the calculations, a collective patient handling exposure estimate of 157 mR results. Similarly, assuming one half of the measured QC exposures for the second department, since only one flood phantom is in use, the collective exposure due to flood phantom QC is estimated to be 53 mR. Together the operations of patient handling and quality control account for 44% of the collective dose equivalent measured by RPB during the quarterly monitoring period. It is important to note that this percentage does not take into consideration exposures incurred when a technologist is involved in assisting a fellow technologist with a patient, as may frequently occur with immobile or infirm patients. Furthermore about 3% of all patient studies conducted during the monitoring period involved procedures other than those enumerated in Table 1. Thus the figure of 44% represents a lower limit on the fraction of exposure arising from patient handling and gamma camera QC. This percentage can be expected to be even greater in other nuclear medicine departments having less imaging floor space per camera, since patient to technologist distances will be reduced accordingly. The remaining exposure (<56%) can be attributed to radiopharmaceutical handling, patient dose preparation, and dose administration, including radioiodine therapies and ablations. Generator elution is specifically excluded as a source of exposure in this instance, since the resident radiopharmacist performed this task.

It is important to note that the technologists participating in the present study routinely perform diagnostic counting and imaging procedures almost exclusively, while other technologists employed in the department have teaching or laboratory work as their primary responsibilities. Although the individuals in both groups are classified as nuclear medicine technologists, the annual radiation exposures received by the second group are significantly smaller than those received by the first. When both groups are combined along with other department or hospital technicians on an institution's list of atomic radiation workers, distinction by job performance may be further occluded. This explains why, in the RPB annual reports on occupational radiation exposures in Canada, the average annual exposure reported for the occupation "radioisotope technician" can be considerably less than that actually received by a nuclear medicine imaging technologist according to TLD service records. For example the RPB report on occupational exposures for 1983[6] indicates that the average whole body dose for isotope technicians in Saskatchewan is 118 mrem annually. Examination of the corresponding RPB quarterly exposure reports for the department monitored, however, reveals that the imaging technologists working there in 1983 received an average exposure approximately three times greater than this.

3. Comparison with Other Published Data

A number of other studies have measured the exposures received by technologists during the performance of their duties. While the majority of this previous work concentrated on the contribution to the total exposure from the preparation and handling of the radiopharmaceuticals[7-10], a few reports of the exposure due to imaging have been published[1-3].

It is a somewhat difficult task to measure the exposure which a technologist receives during the imaging portion of any particular study.

There are several reasons for this, but one major problem is that the exposure rates are small and widely variable. Two different approaches to the problem have been taken.

In a recent study by Boutcher and Haas[3], technologist exposures during imaging were measured by sampling the radiation field with an exposure rate meter at a number of points on the body surface of the technologist. Exposure values for a typical study were then derived by estimating the amount of time that a technologist spent in each of two locations during the study, either near the patient or at the camera console. Further assumptions were made about the percentage of patients that required special attention (eg. holding) to derive a final value for the average exposure per technologist per annum. The average procedural exposure has been calculated here on the basis of procedural exposure measurements and the number of studies performed. Comparative exposure values for procedures common to the Boutcher study and the present investigation are reproduced in Table 7. Also shown are corresponding exposure values obtained by Barrall et al[1]. The latter values were measured directly using a high sensitivity Geiger-Mueller counter in a manner similar to that employed in this study.

The procedures are ranked in order according to exposure from highest to lowest, based on our measurements. General comparisons are difficult to make since a number of factors (eg. the injected activity) vary from study to study. This variability, along with the lack of quoted values for exposure standard deviations, precludes a statistical analysis of the significance of differences between our results and those of other investigators.

Boutcher and Haas found that the gated cardiac studies were responsible for the highest technologist exposure on a procedural basis, as did we. However the value that they quote is about twice as high as ours. This is understandable since they assume that the technologist remains within 6 feet of the patient during the entire study, and is close to the patient for 15 minutes of the 45 minute study. This was rarely the case for studies monitored here since the room in which the cardiac studies are performed allows the technologists to situate themselves more than 6 feet away from the patient.

Brain scans are second on our ranked list. The data of Boutcher support this finding, although as in the case of the cardiac studies, our measured value is considerably lower than theirs. They assume that 35% of the patients require holding and that the technologist spends 10 minutes of the 25 minute study in close contact with the patient. The patient dose used in the Boutcher study was 24 mCi with imaging occuring at two hours post injection. The present study shows that only 3 of 23 patients (13%) were identified as being difficult (ie. required holding). In the present situation brain images are obtained 3 hours after an injection of 20 mCi. The lower patient dose and much lower percentage of patients that were held are likely the major reasons why our reported exposure is lower. It is interesting to note that our value agrees very well with that given by Barrall et al.

The third entry on our ranked list is the brain flow procedure. In this case, our measured value for the exposure agrees very well with that measured by Boutcher and Haas, although it is significantly higher than the value given by Barrall et al.

Table 7: Average Procedural Exposures Reported in the Literature

Procedure	Boutcher & Haas[3]	Barrall et al[1]	present study
Gated Cardiac (rest)	0.89 mR	- mR	0.45 mR
Brain Static	0.80	0.22	0.21
Brain Flow	0.17	0.05	0.19
Bone Scan	0.39	0.54	0.15
Liver Scan	0.07	0.03	0.11
Lung Perfusion	0.07	0.09	0.11

One would expect Boutcher's value to again be higher since the injected activities were the same as for the static brain studies, although in our case the technologist being monitored was always present during the injection of the radiopharmaceutical, and frequently performed the injection. This likely raised our measured exposures somewhat.

The exposure value for the whole body bone scans measured in this study was again lower than the other reported values. The data of Barrall et al was gathered while multiple spot views were taken to cover the whole body. In our case, an automatic scanning system was used which greatly decreases the amount of time that the technologist must spend in close proximity to the patient. Boutcher and Haas assume that the technologists are close to the patient 50% of the time and 6 feet away during the remainder. In the department under study this is certainly not true since the positioning time is much less than half of the total scan time and the patient-technologist observation distance is usually greater than 6 feet.

The difference between our liver and lung perfusion results and those of Boutcher may be explained on the basis of a difference in the injected activity.

There are many factors that might contribute to a difference in technologist exposure among the various nuclear medicine departments involved in the studies referenced above. Since Barrall et al give few details of the protocols used in their study, in many cases it is not possible to understand why our results differ from theirs. In spite of this, the results of the different studies are generally roughly consistent.

As noted earlier, Boutcher and Haas made measurements of the exposure rates at various points of interest near the patients. It is interesting to note that their measured exposure rates display relatively small variations in comparison with the standard deviations of the exposure measurements made in this study. Although they only acquired data during four studies for each procedure, the variation (usually about 20% of the mean value) may be interpreted as reflecting differences in patient uptake. The much larger variation (65% of the mean value, on average) in our measured exposures would thus appear to arise primarily from differences in the specific handling requirements of individual patients, since instrumental uncertainties were at a fairly low (10%) level.

The average daily flood phantom QC exposure of 0.58 mR measured here agrees well with a similar determination by La Fontaine et al[11], who found an average exposure of 0.7 mR. In both cases three gamma cameras were tested, however the department monitored by La Fontaine et al used a single flood source, in contrast to the present situation where such two sources were employed.

H. CONCLUSION

A highly sensitive, portable, direct-reading ion chamber was used to accurately measure procedural radiation exposures to nuclear medicine technologists during patient handling and gamma camera flood phantom quality control. Flood phantom QC and equilibrium gated cardiac studies yielded the largest average exposures at 0.58 and 0.45 mR, respectively. The majority of other procedures resulted in exposures roughly in the range from 0.10 - 0.20 mR.

These findings are in general agreement with a limited number of similar investigations reported in the literature, given our knowledge of the different circumstances and assumptions which prevailed when they were undertaken.

The variability in exposures for all procedures, as gauged by the standard deviation in the measurements, was high, being approximately 65% of the mean exposure. This finding represents significant new information on the distribution of technologist exposures. Considered along with the finding of Boutcher and Haas[3] that for a given procedure, exposure rates measured at fixed distances from patients varied only about 20% from patient to patient, and since our instrumental uncertainties are at the 10% level, it indicates that the primary source of exposure variability stems from the unique handling requirements which each individual patient places on the technologist.

For the majority of diagnostic procedures, difficult patients typically doubled a technologist's exposure. Removal of this patient group from consideration did not noticeably decrease the variability in procedural exposures, however, which remains close to 65% of the mean values. This finding confirms the hypothesis that even among average patients, individual handling requirements result in large variations in technologist exposure.

Comparison of our measurements with those of the TLD service of the Radiation Protection Bureau yields a lower limit for the fraction of total exposure due to patient handling and flood phantom QC of 44% in the department monitored. This figure does not account for situations where two technologists receive coincident exposures from a single patient, however, as can occur when aged or infirm patients are involved. Furthermore the spaciousness of the imaging area in which the present measurements were made renders it very likely that the fraction would be larger in smaller departments.

Finally, a comment on the use of the exposure concept in this report is in order, since from the radiation protection standpoint effective dose equivalent is a more meaningful quantity than exposure. In clinical nuclear medicine, the patient to technologist geometry is continually changing, not only between different procedures, but also within any particular study itself. These geometrical variations, resulting in different dose rates to different body tissues, can be both substantial and rapid, and are not easily measured or otherwise accurately accounted for. Given the scope of the current investigation, no attempt was made to monitor geometrical relationships between the patient and the technologist. In the absence of such information, the effective dose equivalent can only be roughly estimated. For nuclear medicine imaging, such a rough estimate indicates that the effective dose equivalent equals exposure times 0.5–0.8 rem/R.

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APPENDIX A

DIAGNOSTIC AND FLOOD PHANTOM QUALITY CONTROL PROTOCOLS

1. Brain Studies

Radiopharmaceutical: Tc-99m-glucoheptonate
Activity: 20 mCi
Route: intravenous injection

1.1 Brain Flow

The patient is first positioned on the tomography scanning bed and the camera is positioned beneath his head. A tourniquet is applied to his arm and he receives the Tc-99m-glucoheptonate injection. The injection is an inseparable part of the imaging procedure and the monitored technologist is always present to assist the technologist administering the injection. When the tourniquet is released, the radiopharmaceutical flows into the brain, and the imaging proceeds for 60 seconds. It is often necessary for the technologist to hold the patient's head still. The entire procedure takes about 5 minutes.

A brain scan or tomographic study routinely follows 3 hours after the brain flow procedure.

1.2 Brain Scan

The patient returns 3 hours after the brain flow and is positioned on a stool with his head against the camera. Anterior, posterior, right and left lateral views are taken. The technologist is sometimes required to hold a difficult patient in position. The procedure takes approximately 30 minutes.

1.3 Brain Tomography

The patient returns 3 hours after the brain flow and is positioned on the tomography bed. His head is taped into position to prevent movement. This is the only positioning required and it is rarely necessary for the technologist to contact the patient during imaging. This procedure takes about 30 minutes.

2. Cardiac Wall Motion Study

Radiopharmaceutical: Tc-99m
Activity: 20 mCi
Route: intravenous injection

The patient receives two injections for this study. The first is non-radioactive, containing stannous chloride which will allow the Tc-99m administered in the second injection to attach to and tag the patient's red blood cells.

After the first injection, the patient is positioned on the scanning bed with the gamma camera over his chest. The Tc-99m injection is administered with the patient in position and the imaging begins immediately following the injection. Four views are taken: anterior, left anterior oblique at 40 and 70 degrees, and left lateral. It is rarely necessary for the technologist to contact the patient during imaging except to position him for each view.

The procedure takes from 30 to 60 minutes.

3. Gallium Scan

Radiopharmaceutical: Ga-67 citrate
Activity: 4 mCi
Route: intravenous injection

A scan is done of the whole body or of a specific part of the body at one or more of the following post-injection times: 6, 24, 48, or 72 hours. In the present study only whole body scans were monitored. The patient is positioned on a scanning bed and the camera is placed below him. He lies once on his back and once on his stomach to obtain both anterior and posterior views. Patient contact is rarely necessary during imaging. The procedure takes about 1 hour.

4. Lung Perfusion

Radiopharmaceutical: Tc-99m-macroaggregated albumin
Activity: 3 mCi
Route: intravenous injection

Immediately following the injection of Tc-99m-MAA, the patient is positioned sitting up on a stretcher or stool. Six views are taken: anterior, right anterior oblique, left anterior oblique, posterior, right posterior oblique, and left posterior oblique. It is often necessary for the technologist to assist the patient in sitting up or remaining still. The procedure takes about 20 minutes.

This test is often followed by a lung ventilation study.

5. Lung Ventilation

Radiopharmaceutical: Xe-133 gas
Activity: 10 - 20 mCi
Route: inhalation

This procedure always immediately follows a lung perfusion study, so that the radioactivity from the previous Tc-99m-MAA injection and that from the xenon administered for the lung ventilation both contribute to the exposure that the technologist receives.

The patient sits on a stool or stretcher with his back positioned against the camera. The technologist places a mouthpiece over the patient's mouth and nose which is attached to a xenon delivery system placed a feew feet away. The mouthpiece is usually held in place by the technologist while the patient breathes a mixture of xenon and oxygen. It is then removed, but the imaging continues for several minutes afterwards. The technologist generally stays close to the patient during these last few minutes to keep him still. The entire procedure takes about 20 minutes.

6. Liver Studies

Radiopharmaceutical: Tc-99m sulfur colloid
Activity: 5 mCi
Route: intravenous injection

Ten to fifteen minutes following the injection of Tc-99m sulfur colloid, either a scan or tomographic study is done.

6.1 Liver Scan

The patient is positioned sitting up on a stool or stretcher. It is often necessary for the technologist to hold more difficult patients in position for each view. Five views are generally required: right lateral, left lateral, anterior with a lead marker, anterior without a marker, and posterior. The procedure takes about 20 minutes.

6.2 Liver Tomography

The patient is positioned on the tomography bed with his arms secured above his head. It is rarely necessary for the technologist to contact the patient after the initial positioning. This procedure takes about 30 minutes in total.

7. Bone Studies

Radiopharmaceutical: Tc-99m-methylene diphosphonate
Activity: whole body - 20 mCi, spot views - 15 mCi
Route: intravenous injection

Two hours after the injection of Tc-99m-MDP, the patient returns for a whole body bone scan, a spot bone scan, or both.

7.1 Whole Body Bone Scan

The patient is positioned on a scanning bed in a prone position. Generally the patient lies once on his back and once on his stomach with the camera below the bed each time to obtain a posterior and an anterior view. It is rarely necessary for the technologist to contact the patient during imaging except to assist him to turn over. This study takes about 45 minutes.

7.2 Spot Bone Scan

The patient is positioned so that the particular part of the body to be imaged is in front of the camera. Depending on the required position and the condition of the patient, it is sometimes necessary for the technologist to hold the patient in position. Although the number of views and the time taken for each view vary widely, an average of four views are taken for each body part and this requires about 20 minutes.

8. Thallium Heart Study

Radiopharmaceutical: Tl-201
Activity: 2.2 mCi
Route: intravenous injection

The patient is exercised on a treadmill in the stress lab and given an injection of Tl-201. The patient is then taken to the imaging room in a wheelchair. The monitoring of exposure does not begin until the patient enters the imaging room. The patient is positioned on the scanning below the camera. Three views are done of the heart: left anterior oblique at 40 and 70 degrees, and anterior. The technologist is generally only required to contact

the patient to position him for each view. The imaging and positioning time is about 45 minutes.

The patient is often required to return 3 hours later for further imaging to obtain views illustrating the redistribution of Tl-201 in the heart. The same procedure is followed as before, and usually the same 3 views are taken. The imaging and positioning time is again about 45 minutes.

9. Thyroid Studies

Radiopharmaceutical: I-131
Activity: 0.05 mCi
Route: oral

These test are done over two days. On the first day, the patient is given liquid containing I-131. Twenty-four hours later, he returns for both of the following tests.

9.1 Thyroid Uptake Evaluation

The patient is brought into a small office by the technologist and is seated on a chair. The technologist sits directly across from the patient. A counting probe is positioned in front of the patient's neck to measure the amount of I-131 taken up by the thyroid gland, and then positioned over the thigh to measure the bodily uptake. The entire procedure takes about 6 minutes.

9.2 Thyroid Scan

This procedure immediately follows the uptake evaluation. The technologist positions the patient on the scanning bed with the rectilinear scanner head above his neck. It is rarely necessary for the technologist to contact the patient during imaging. After the scan is completed, the technologist spends a few minutes probing the patient's thyroid by hand to locate any abnormalities, and then marks the location of these on the film. The entire procedure takes about 15 minutes.

10. Flood Phantom Quality Control

This procedure is performed on a daily basis. The two flood phantoms are each first filled with water and 5 mCi Tc-99m as pertechnetate, and agitated to promote uniform mixing of the activity. This part of the procedure is carried out in the laboratory (see Figure 1). When ready, the phantoms are carried to the imaging room, where the larger one is laid on the standard low energy collimator of one of the large field of view gamma cameras, whose head is facing upwards, and the other is similarly placed on the standard field of view camera. A set of three images is then obtained for each camera as follows:

(1) nothing between flood and collimator, 3 million count image
(2) four quadrant bar phantom inserted between flood and collimator, 3 million count image
(3) orthogonal hole phantom inserted between flood and collimator, 1 million count image

This imaging process is then repeated using the larger phantom for the remaining large field of view camera, after which both flood sources are retired to a lead-lined storage container.

APPENDIX B

DATA RECORDING FORMS

1. Diagnostic Procedures

The form reproduced in Figure B1 was used to record exposure readings and ancillary information for diagnostic studies.

The upper portion of the form contains administrative data which is largely self-explanatory. Each sheet has a sequential identification number, entered in the top right corner, to uniquely identify it. The date and time of the procedure, along with the department's patient identification number, appear next. These fields are followed by the STRAD number, a unit identifier from 1 - 3, the attending technologist's initials (two only), and the two letter procedure code, as given in Table 1. The number of imaging views attempted, radiopharmaceutical and activity used, and time and date of administration round out the upper portion of the form.

The lower portion of the form contains the measurement data. The patient positioning difficulty, as rated by the attending technologist, is followed by the background exposure reading and length of time over which it was obtained, and by the technologist exposure reading and monitoring time as discussed in Section E.1. The last fields for temperature and atmospheric pressure record information used in correcting the STRAD response.

2. Flood Phantom Quality Control

The form shown as Figure B2 was used to record information relating to flood phantom quality control exposures. The top part of the form contains a sequential identification number followed by fields for the STRAD identifier, date, technologist, and activity used. The interpretation of information entered in these fields is the same as for the diagnostic procedures. The time intervals spent in the lab preparing the flood and in the imaging room positioning it for the cameras appear next, along with background readings for each locale taken over a 30 minute interval. The technologist exposure, temperature, and atmospheric pressure fields complete the form.

IMAGING EXPOSURE DATA SHEET No.____

Date: _____ (dd-mm-yy) Time: _____ (hh:mm)

Patient NM Number: _____ STRAD No. : _____

Technologist: _____

Procedure: _____ No. Views: _____

(if applicable)

Radiopharmaceutical: _____ Activity: _____ (MBq)

Time & Date of Administration: _____

Positioning Difficulty: _____

(1-5, 1 = extremely easy, 3 = average, 5 = extremely difficult)

Background Reading: _____ (mR) Time: _____ (min)

Imaging Reading: _____ (mR) Time: _____ (min)

Temperature: _____ (C) Pressure: _____ (mm Hg)

Notes:

Figure B1: Imaging Exposure Data Sheet

FLOOD PHANTOM EXPOSURE DATA SHEET No._____

Date: _____ STRAD No.: _____

Technologist: _____ Activity: _____ (MBq)

Time in Lab: _____ (min)

Time in Imaging Room: _____ (min)

30 Min Background Reading in Lab: _____ (mR)

30 Min Background Reading in Imaging Room: _____ (mR)

Exposure Reading: _____ (mR)

Figure B2: Flood Phantom Exposure Data Sheet

ANALYSIS SOFTWARE LISTINGS

Analysis software developed within the project processing facility of the SMART Data Manager is listed below. Comment statements within each program are used to identify the variables appearing and to indicate the overall logic flow. A full description of the operation of the individual program statements can be found in the user documentation for the SMART Data Manager[5].

1. Diagnostic Procedures

1.1 Corrected Exposure Readings

The following program opens the diagnostic exposures data base, and for each record calculates the corrected exposure reading, which it then writes back into the record.

```
comment
comment  calculate the corrected imaging reading and fill in [19]
comment
comment  EXPOSE data:
comment  [5]  = strad number
comment  [13] = background reading
comment  [14] = background measurement time
comment  [15] = imaging reading
comment  [16] = imaging measurement time
comment  [18] = barometric pressure
comment  [19] = corrected reading
comment
comment  %0   = number of records
comment  %1   = record number
comment
comment  $n   = background corrected reading
comment  $cf  = strad Co-57 calibration factor
comment  $cr  = corrected reading
comment
clear
wait 1 Loading files...
unload all
load expose screen expose
order key [1]
let %0 = records
wait 2 There are %0 records.
%1 Enter starting sheet number:
if %1 <= 0 then jump error
if %1 > %0 then jump done
label start
wait Record: %1
goto record rec-number %1
let $n = [15] - ( [13] * [16] / [14] )
if [14] <> 0 then jump skip
comment Give record number if division by zero
message Sheet %1 has bad data.
let $n = 0
```

```
label skip
if $n < 0 then let $n = 0
if [5] = 1 then let $cf = 1.00
if [5] = 2 then let $cf = 1.16
if [5] = 3 then let $cf = 1.16
let $cr = 760 / [18] * $cf * $n
let [19] = round($cr,2)
if %1 = %0 then jump done
let %1 = %1 + 1
jump start
label error
message Bbbblllppp!!!
label done
```

1.2 Mean and Standard Deviation

Using the corrected exposure readings, the next program calculates the mean exposure and standard deviation for each of the diagnostic procedures monitored, and writes this information to a data base file.

```
comment
comment  calculate the mean and standard deviation of corrected
comment  exposure readings for each imaging procedure
comment
comment  EXPOSE data:
comment  [7]  = procedure code
comment  [16] = imaging measurement time
comment  [19] = corrected reading
comment
comment  STANDEV data:
comment  [3]  = number of entries for procedure
comment  [4]  = mean reading
comment  [5]  = standard deviation in readings
comment  [6]  = mean imaging time
comment
comment  %0   = number of records in expose file
comment  %1   = record number in expose file
comment  %2   = procedure code
comment  %3   = number of entries for procedure
comment
comment  $s   = sum of readings
comment  $ss  = sum of squared readings
comment  $st  = sum of imaging times
comment  $n   = number of standev records/procedure code
comment  $i   = loop counter for standev records
comment  $mean = mean reading
comment  $avertime = mean imaging time
comment  $thresh = 2, number of readings needed for s.d. calculation
comment  $fini = no more expose records flag
comment  $reading = corrected reading
comment  $time = imaging time
comment  $sd  = standard deviation in readings
comment
clear
let $thresh = 2
wait 1 Loading files...
```

```
unload all
activate standev screen standev
activate expose screen expose
comment
comment Clean up the standev file first
comment
wait 1 Preprocessing standev file...
goto file standev screen standev
goto record rec-number 1
let $n = records
let $i = 0
label tstart
let $i = $i + 1
if $i > $n then jump texit
let [3] = 0
let [4] = 0
let [5] = 0
let [6] = 0
goto record next
jump tstart
label texit
comment
comment Process expose data, ordered by procedure
comment
wait 1 Now processing exposure data...
goto file expose screen expose
order key [7]
let %0 = records
wait 2 There are %0 records.
let %1 = 0
let %2 = "  "
let $fini = 0
label start
let %1 = %1 + 1
if %1 > %0 then jump eof
goto record rec-number %1
let $n = [7]
let $reading = [19]
let $time = [16]
if "%2" = "  " then jump brk0
if "%2" = $n then jump nobrk
label breakpoint
if %3 < $thresh then jump nocalc1
let $mean = $s / %3
let $avertime = $st / %3
let $sd = $ss - ( $s * $s / %3)
let $sd = $sd / ( %3 - 1 )
if $sd < 0 then let $sd = 0
let $sd = sqrt( $sd )
label nocalc1
goto file standev screen standev
order key [1]
find [1] equal "%2" options g
if [1] <> "%2" then jump notfound
let [3] = %3
if %3 < $thresh then jump nocalc2
```

```
let [4] = round( $mean, 3 )
let [5] = round( $sd, 3 )
let [6] = round( $avertime, 0)
label nocalc2
goto file expose screen expose
order key [7]
if $fini = 1 then jump done
label brk0
let %2 = $n
let %3 = 0
let $s = 0
let $ss = 0
let $st = 0
wait 2 Procedure: %2
label nobrk
let %3 = %3 + 1
let $s = $s + $reading
let $ss = $ss + ( $reading * $reading )
let $st = $st + $time
jump start
label eof
let $fini = 1
jump breakpoint
label notfound
let %1 = %1 - 1
message Procedure group %2 not found
message Offending exposure record is %1, (ordered by [7])
label done
goto file expose screen expose
order key [1]
save
message Project terminating...
```

1.3 Positioning Difficulty

This program uses the corrected exposure readings to determine procedural mean exposures and standard deviations separately for two classes of patients handled, those considered routine (difficulty rating 1 -3) and those considered difficult (difficulty rating 4 or 5). Output is written to a database file.

```
comment
comment  calculate the mean and standard deviation of corrected
comment  exposure readings for average and difficult patients
comment  for each imaging procedure
comment
comment  EXPOSE data:
comment  [7]  = procedure code
comment  [12] = positioning difficulty (1-5)
comment  [16] = imaging measurement time
comment  [19] = corrected reading
comment
comment  POSITION data:
comment  [3]  = number of entries for procedure
comment  [4]  = mean reading
comment  [5]  = standard deviation in readings
```

```
comment  [6]  = mean imaging time
comment
comment  %0   = number of records in expose file
comment  %1   = record number in expose file
comment  %2   = positioning group (Average/Difficult)
comment  %3   = number of entries for procedure
comment  %4   = procedure code
comment  %5   = positioning difficulty (1-5)
comment
comment  $s   = sum of readings
comment  $ss  = sum of squared readings
comment  $st  = sum of imaging times
comment  $n   = positioning difficulty
comment  $pn  = procedure code
comment  $i   = loop counter for position records
comment  $mean = mean reading
comment  $avertime = mean imaging time
comment  $tave = 4, minimum no. of readings for average s.d. calc.
comment  $tdif = 2, minimum no. of readings for difficult s.d. calc.
comment  $thresh = either $tave or $tdif
comment  $fini = no more expose records flag
comment  $flag = average/difficult positioning group flag
comment  $pos = positioning group (Average/Difficult)
comment  $reading = corrected reading
comment  $time = imaging time
comment  $sd  = standard deviation in readings
comment
clear
let $tave = 4
let $tdif = 2
wait 1 Loading files...
unload all
activate position screen position
activate expose screen expose
comment
comment Clean up the positioning file first
comment
wait 1 Preprocessing positioning file...
goto file position screen position
goto record rec-number 1
let $n = records
let $i = 0
label tstart
let $i = $i + 1
if $i > $n then jump texit
let [3] = 0
let [4] = 0
let [5] = 0
let [6] = 0
goto record next
jump tstart
label texit
comment
comment Process expose data, ordered by procedure, difficulty
comment
wait 1 Now re-keying exposure data to [7;12] ...
```

```
goto file expose screen expose
key delete [7]
key add [7;12]
key update
order key [7;12]
wait 1 Now processing exposure data...
let %0 = records
wait 2 There are %0 records.
let %1 = 0
let $flag = -1
let $fini = 0
label start
let %1 = %1 + 1
if %1 > %0 then jump eof
goto record rec-number %1
let $n = [12]
if $n < 1 or $n > 5 then jump badrange
let $pn = [7]
let $reading = [19]
let $time = [16]
if $flag = -1 then jump brk0
if "%4" <> $pn then jump breakpoint
if $flag = 0 then jump testlow
if $n > 3 then jump nobrk
let %5 = $n
message Procedure %4, Positioning %2: Difficulty %5 out of order
label printrec
message Offending exposure record is %1, (ordered by [7;12])
jump done
label badrange
let %5 = $n
message Procedure %4: Difficulty %5 out of range
jump printrec
label testlow
if $n < 4 then jump nobrk
label breakpoint
let $thresh = $tave
if $flag = 1 then let $thresh = $tdif
if %3 < $thresh then jump nocalc1
let $mean = $s / %3
let $avertime = $st / %3
let $sd = $ss - ( $s * $s / %3)
let $sd = $sd / ( %3 - 1 )
if $sd < 0 then let $sd = 0
let $sd = sqrt( $sd )
label nocalc1
goto file position screen position
order key [1;2]
find [1] equal "%4" options gi
if $flag = 1 then goto record next
if not ([1]=="%4") or not([2]=="%2") then jump notfound
let [3] = %3
if %3 < $thresh then jump nocalc2
let [4] = round( $mean, 2 )
let [5] = round( $sd, 2 )
let [6] = round( $avertime, 0 )
```

```
label nocalc2
goto file expose screen expose
order key [7;12]
if $fini = 1 then jump done
label brk0
let $flag = 0
if $n > 3 then let $flag = 1
let $pos = "Average"
if $flag = 1 then let $pos = "Difficult"
let %2 = $pos
let %4 = $pn
let %3 = 0
let $s = 0
let $ss = 0
let $st = 0
wait 2 Procedure: %4, Positioning: %2
label nobrk
let %3 = %3 + 1
let $s = $s + $reading
let $ss = $ss + ( $reading * $reading )
let $st = $st + $time
jump start
label eof
let $fini = 1
jump breakpoint
label notfound
let %1 = %1 - 1
message Procedure %4, Positioning %2: not found
jump printrec
label done
goto file expose screen expose
key delete [7;12]
key add [7]
key update
save
message Project terminating...
```

1.4 Individual Technologist Exposures

The following program calculates procedural exposure mean values and standard deviations for individual technologists, starting from the corrected exposure readings. Output is again directed to a database file.

```
comment
comment  calculate the mean and standard deviation of corrected
comment  exposure readings for each imaging procedure, for each
comment  technologist
comment
comment  EXPOSE data:
comment  [6]  = technologist code
comment  [7]  = procedure code
comment  [16] = imaging measurement time
comment  [19] = corrected reading
comment
comment  TECH data:
comment  [1]  = procedure code
```

```
comment  [2]  = technologist code
comment  [3]  = number of entries for procedure
comment  [4]  = mean reading
comment  [5]  = standard deviation in readings
comment  [6]  = mean imaging time
comment
comment  %0   = number of records in expose file
comment  %1   = record number in expose file
comment  %2   = technologist code
comment  %3   = number of entries for procedure
comment  %4   = procedure code
comment
comment  $s   = sum of readings
comment  $ss  = sum of squared readings
comment  $st  = sum of imaging times
comment  $n   = number of tech records/technologist code
comment  $pn  = procedure code
comment  $i   = loop couter for tech records
comment  $mean = mean reading
comment  $sd  = standard deviation in readings
comment  $avertime = mean imaging time
comment  $reading = corrected exposure reading
comment  $time = imaging time
comment  $fini = no more expose records flag
comment
clear
wait 1 Loading files...
unload all
activate tech screen tech
activate expose screen expose
comment
comment Clean up the tech file first
comment
wait 1 Preprocessing tech file...
goto file tech screen tech
goto record rec-number 1
let $n = records
let $i = 0
label tstart
let $i = $i + 1
if $i > $n then jump texit
let [3] = 0
let [4] = 0
let [5] = 0
let [6] = 0
goto record next
jump tstart
label texit
comment
comment Processing exposure data...
comment
wait 1 Now re-keying exposure data to [7;6] ...
goto file expose screen expose
key delete [7]
key add [7;6]
key update
```

```
order key [7;6]
let %0 = records
wait 2 There are %0 records.
let %1 = 0
let %2 = "  "
let $fini = 0
label start
let %1 = %1 + 1
if %1 > %0 then jump eof
goto record rec-number %1
let $n = [6]
let $pn = [7]
let $reading = [19]
let $time = [16]
if "%2" = "  " then jump brk0
if "%4" <> $pn then jump breakpoint
if "%2" = $n then jump nobrk
label breakpoint
if %3 < 1 then jump nocalc1
let $mean = $s / %3
let $avertime = $st / %3
let $sd = $ss - ( $s * $s / %3)
if %3 > 1 then let $sd = $sd / ( %3 - 1 )
if $sd < 0 then let $sd = 0
let $sd = sqrt( $sd )
label nocalc1
goto file tech screen tech
order key [1;2]
find [1] equal "%4" options gi
find [2] equal "%2" options i
if [1] <> "%4" or [2] <> "%2" then jump notfound
let [3] = %3
if %3 < 1 then jump nocalc2
let [4] = round( $mean, 2 )
let [5] = round( $sd, 2 )
let [6] = round( $avertime, 2 )
label nocalc2
goto file expose screen expose
order key [7;6]
if $fini = 1 then jump done
label brk0
let %2 = $n
let %4 = $pn
let %3 = 0
let $s = 0
let $ss = 0
let $st = 0
wait 2 Procedure: %4, Techtoid: %2
label nobrk
let %3 = %3 + 1
let $s = $s + $reading
let $ss = $ss + ( $reading * $reading )
let $st = $st + $time
jump start
label eof
let $fini = 1
```

```
jump breakpoint
label notfound
let %1 = %1 - 1
message Procedure %4, Techtoid %2: not found
message Offending exposure record is %1, (ordered by [7;6])
label done
goto file expose screen expose
key delete [7;6]
key add [7]
key update
save
message Project terminating...
```

2. Flood Phantom Quality Control

2.1 Corrected Exposure Readings

The following program opens the flood phantom QC data base, and calculates corrected exposure readings for each record, writing the result back into the record.

```
comment
comment  calculate the corrected QC reading and fill in [12]
comment
comment  QCEXPOSE data:
comment  [2]  = strad number
comment  [7]  = time in hot lab
comment  [8]  = time in imaging area
comment  [9]  = 30 minute hot lab background reading
comment  [10] = 30 minute background reading in imaging area
comment  [11] = exposure reading
comment  [12] = corrected exposure reading
comment  [13] = barometric pressure
comment
comment  %0   = number of records
comment  %1   = record number
comment  $n   = background corrected reading
comment  $cf  = strad Co-57 calibration factor
comment  $cr  = corrected reading
comment
clear
wait 1 Loading files...
unload all
load qcexpose screen qcexpose
order key [1]
let %0 = records
wait 2 There are %0 records.
%1 Enter starting sheet number:
if %1 <= 0 then jump error
if %1 > %0 then jump done
label start
wait Record:  %1
goto record rec-number %1
let $n = [11] - ([10] * [8]/30) - ([9] * [7]/30)
if $n < 0 then let $n = 0
if [2] = 1 then let $cf = 1.00
```

```
if [2] = 2 then let $cf = 1.16
if [2] = 3 then let $cf = 1.16
let $cr = 760/[13] * $cf * $n
let [12] = round( $cr, 2 )
if %1 = %0 then jump done
let %1 = %1 + 1
jump start
label error
message Error, starting sheet number must be greater than 0.
label done
```

2.2 Exposure Mean Value and Standard Deviation

This program determines the mean QC exposure and standard deviation from the corrected QC exposure readings, and writes the results to a data base file.

```
comment
comment  calculate the mean and standard deviation of
comment  corrected exposure readings for flood phantom QC
comment
comment  QCEXPOSE data:
comment  [12] = corrected exposure reading
comment
comment  QCMEAN data:
comment  [1]  = number of records
comment  [2]  = mean reading
comment  [3]  = standard deviation in readings
comment
comment  %0   = number of records in qcexpose file
comment  %1   = current record in qcexpose file
comment
comment  $n   = exposure reading
comment  $fini = end of records flag
comment  $sd  = standard deviation in readings
comment  $s   = sum of elements
comment  $ss  = sum of squared elements
comment
clear
wait 1 Loading files...
unload all
load qcmean screen qcmean
load qcexpose screen qcexpose
let %0 = records
wait 2 There are %0 records.
let %1 = 0
let $s = 0
let $ss = 0
let $fini = 0
label start
let %1 = %1 + 1
if %1 > %0 then jump eof
goto record rec-number %1
jump go
label lastone
let $mean = $s / %0
let $sd = $ss - ($s * $s / %0)
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let $sd = $sd / (%0 - 1)
let $sd = sqrt ( $sd )
goto file qcmean screen qcmean
goto record rec-number 1
let [1] = %0
let [2] = round( $mean, 2 )
let [3] = round( $sd, 2 )
goto file qcexpose screen qcexpose
if $fini = 1 then jump end
label go
let $n = [12]
let $s = $s + $n
let $ss = $ss + ($n * $n)
jump start
label eof
let $fini = 1
jump lastone
label end
message Project terminating...
```